LONG TERM EFFECTS OF LIMING AN ACID SCOTT LOAM ON YIELD AND PHOSPHORUS NUTRITION OF WHEAT AND BARLEY

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INTRODUCTION

Soil acidity, as an agricultural problem, has received little attention until quite recently in Western Canada. There are approximately one million hectares of acid soils in Saskatchewan with surface pH at or below 5.5. The greatest concentration of acid soils occurs in the west-central and northwestern part of the province in the Dark Brown and Black soil zones. The degree of acidity indicated above could reduce the yields of a number of grain and forage crops because of nutritional and toxicity problems.

Acid soils in western Saskatchewan generally have low available phosphorus levels which restricts crop yields, and most crops respond quite strongly to phosphate fertilizers. Studies on a number of Canadian soils have shown that soluble and exchangeable aluminum in acid soils may restrict plant growth and yields (Hoyt and Nyborg 1971, 1972; Hoyt and Webber 1974; Webber *et al*. 1982). Studies on acid soils in Alberta and northeastern British Columbia by Rice *et al*. (1977) have shown that nitrogen fixation and alfalfa yields decrease sharply when soil pH decreases below 6.0.

Several measures may be used to improve crop production on acid soils. The growing of acid-tolerant crops can improve yields. However, at the present time there are few varieties of suitable field crops bred for acid tolerance in Western Canada. Deep banding of nitrogen fertilizers may slow down the rate of surface soil acidification, but would not improve acid soils. Liming, although a relatively costly treatment initially, is the most effective remedy for the problem of soil acidity.

Studies in Alberta and northeastern British Columbia have shown that lime application on soils of pH 5.1-5.5 can substantially increase the yields of alfalfa, red clover, barley and rapeseed (Penney *et al*. 1977). The investigations reported on in this paper were undertaken to determine the response of several crops to liming of an acid Dark Brown soil in west-central Saskatchewan, and to determine how long a single application of lime would be effective in increasing crop yields under the climatic conditions of the area.

METHODS AND MATERIALS

The experiments were located on a Dark Brown eluviated Chernozem Scott loam soil on the Experimental Farm at Scott, Saskatchewan. Field plots were placed on three sites separated by distances of up to approximately 1 km. Lime was applied as $Ca(OH)_2$ and incorporated to a depth of approximately 15 cm.

Gypsum was also applied as a calcium treatment. Lime requirement for a given pH was determined by adding several rates of $Ca(OH)_2$ to soil-water mixtures and measuring the pH after equilibration for 3 days. Phosphate fertilizer was applied at several rates with the seed for wheat and barley and banded below - to the side of the seed for rapeseed, using monoammonium phosphate 11-48-0 and treblesuperphosphate 0-45-0. Crops were usually sown on fallow without added N. Occasionally when crops were sown on stubble land, additional nitrogen was applied to the plot area when required, on the basis of a soil test. The soils contained adequate levels of K and S.

Treatments were arranged in a split plot design with four replicates, with the lime, gypsum and no lime as main plots and phosphate treatments as sub-plots for each crop. Sub-plots were 1 X 6.7 m in size. Yields were obtained by harvesting 2 or 4 rows, 6.2 m long from each sub-plot.

On site 1, lime was applied in the spring of 1963 at rates of 4480 and 6720 kg/ha. On site 2, lime was applied at 4480 kg/ha in the fall of 1965. On site 3 the lime rates were 2240, 3360, 4480 and 8960 kg/ha. Gypsum was applied on the three sites at a rate of Ca equal to that in 4480 kg $Ca(OH)_2$/ha. During the course of the experiments, tillage was done only in the direction of the long axis of the subplots, so as to minimize mixing of the adjacent treatments. Phosphate treatments were applied to the same sub-plots each crop year.

Soil samples were taken from the plots in the spring prior to seeding for chemical analyses. Soil pH was measured in saturated soil paste. Available P and NO_3-N were determined in 0.5 M $NaHCO_3$ extracts. Soluble Al and Mn were extracted with 0.02 M $CaCl_2$ and determined by atomic absorption. Exchangeable Al and Mn were determined in 1 NKCl and $BaCl_2$ extracts, respectively. Aluminum was also extracted with ammonium acetate and Mn with D.T.P.A.

Grain samples were digested with concentrated H_2SO_4 and H_2O_2 and N and P determined calorimetrically by autoanalyzer. Except where indicated otherwise, data presented showing the response to fertilizer (yield, protein, P) are the means of all the P fertilizer treatments.

RESULTS AND DISCUSSION

Soil pH

On site 1, a single application of $Ca(OH)_2$ at a rate of 4480 kg/ha maintained the increased soil pH levels at or above 6.0 for a period of 19 years (Table 1). With the 6720 kg/ha rate, pH remained above 6.0 for 20 years. On sites 2 and 3, with slightly higher initial soil pH levels, the 4480 kg/ha $Ca(OH)_2$ applications kept the pH above 6.0 for periods of 16 and 14 years, respectively. On site 3, where 8960 kg/ha was applied, there was very little decrease in pH from the highest level attained over a period of 14 years. Apparently the leaching of Ca is very slow under the climatic conditions of the area. Gypsum did not increase soil pH.

Soil NO_3-N and available P levels

The application of lime to the soil on sites 1 and 3 did not appear to have any consistent effect on soil NO_3-N (Figures 1 and 2). Soil moisture

Table 1. Effect on soil pH of a single application of lime on an acid Scott loam.

Saturated soil pH*

Treatment	Site 1							
	1966	1970	1972	1974	1976	1980	1982	1983
Check	5.2	5.6	5.3	5.4	4.9	5.5	5.0	5.3
Gypsum	5.1	5.5	5.2	5.0	4.8	5.0	4.9	4.8
$Ca(OH)_2$ 4480	6.6	6.6	6.4	6.0	6.1	6.0	5.9	5.9
$Ca(OH)_2$ 6720	7.6	7.6	6.8	6.8	6.8	6.6	6.3	6.7

Treatment	Site 2						
	1966	1971	1972	1975	1977	1979	1981
Check	5.7	6.1	6.0	5.1	5.3	5.6	5.4
Gypsum	5.3	5.6	5.6	5.4	5.5	5.4	5.6
$Ca(OH)_2$ 4480	7.2	6.6	6.6	7.0	6.5	6.2	6.5

Treatment	Site 3						
	1970	1972	1976	1978	1980	1982	1982
Check	5.5	5.4	5.0	5.3		5.5	5.3
Gypsum	5.6	5.5	5.4	5.4		5.5	5.4
$Ca(OH)_2$ 2240	5.8	6.0	5.9	5.8	5.6	6.3	5.8
$Ca(OH)_2$ 3360	7.4	7.2	6.2	6.2	6.4	6.4	5.9
$Ca(OH)_2$ 4480	7.1	6.5	6.2	6.2	6.7	6.5	6.3
$Ca(OH)_2$ 8960	7.8	7.6	7.3	7.5	7.2	7.5	7.5

*0-15 cm depth

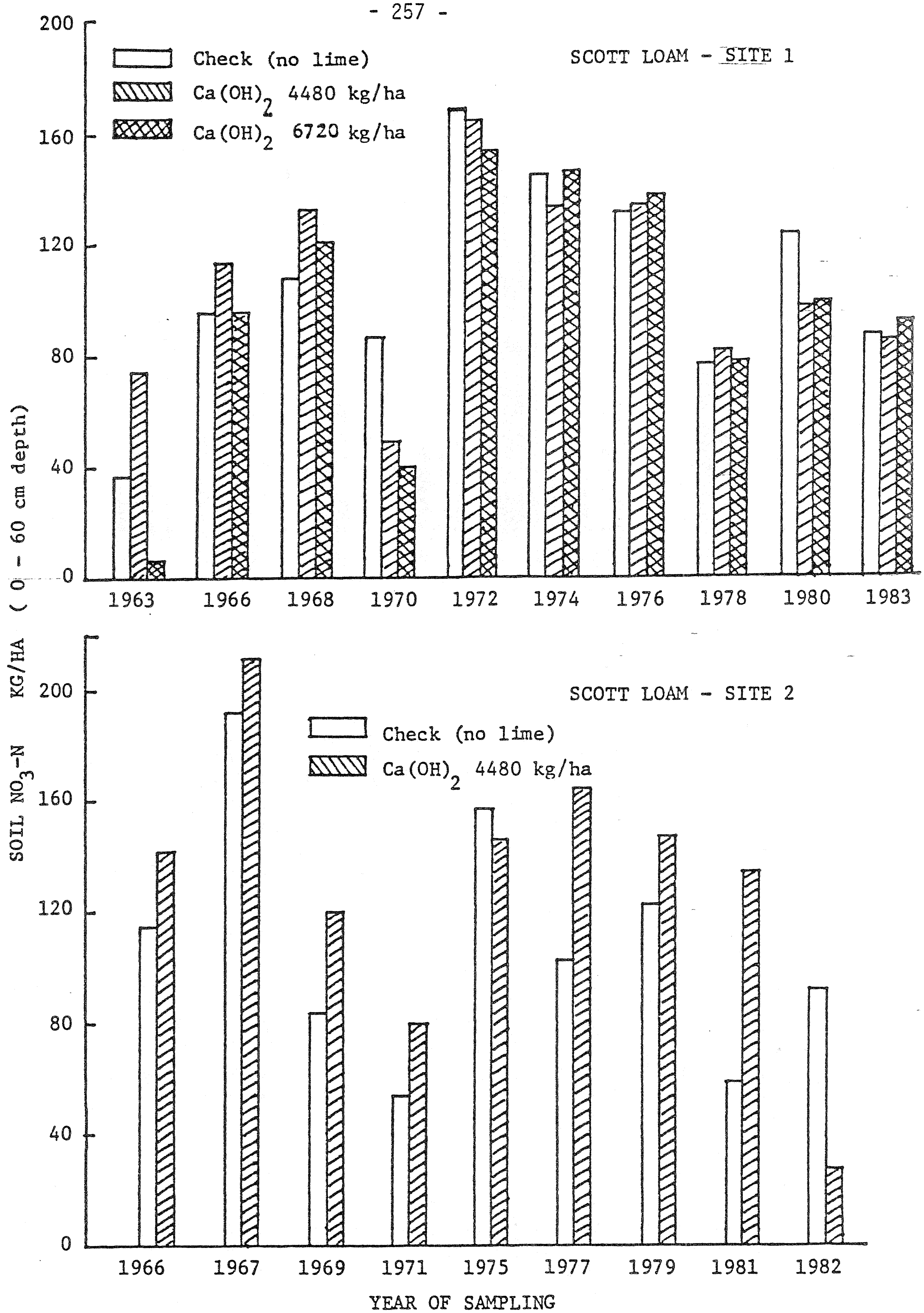

Figure 1. The effect of lime application on the NO_3-N contents in Scott loam.

Figure 2. The effect of lime application on the NO_3-N contents in Scott loam.

conditions probably affected mineralization of soil N to a much greater degree than the lime. On site 2, however, as shown in Figure 1, NO_3-N levels were generally higher in limed plots. Nyborg and Hoyt (1978) found that soil acidity did not restrict mineralization of organic N, although liming may increase mineralization of N, generally as a temporary effect.

Available ($NaHCO_3$-extractable) P levels in Scott loam were increased consistently by liming on the three sites as shown in Figure 3.

Aluminum and Manganese

The application of lime sharply reduced or eliminated soluble and exchangeable Mn and Al levels in the soil as determined by several extraction procedures (Table 2). Soluble Al has been shown to be an important yield restricting factor in acid soils (Webber et al. 1982). Levels of soluble Mn and Al above 20 and 1.0 ppm, respectively, are considered to be toxic to sensitive crops such as barley. It would appear than soluble Mn may be more important than Al in the Scott loam soil

Grain yields

Grain yield data are presented in Tables 3, 4 and 5. During the 21 year period following one application of lime, average yield increases for nine crops each of wheat and barley from the 4480 and 6720 kg/ha rates of lime were 26-33% and 48-55%, respectively. In 1983, wheat yields were increased by 41% by lime applied at 4480 kg/ha in 1963 on site 1 (Table 3), and barley yields were increased 36% by the same rate of lime applied on site 3 in 1969 (Table 5). Similar yield increases have been obtained during the experimental period on site 2 (Table 4). Barley and rapeseed yields have increased

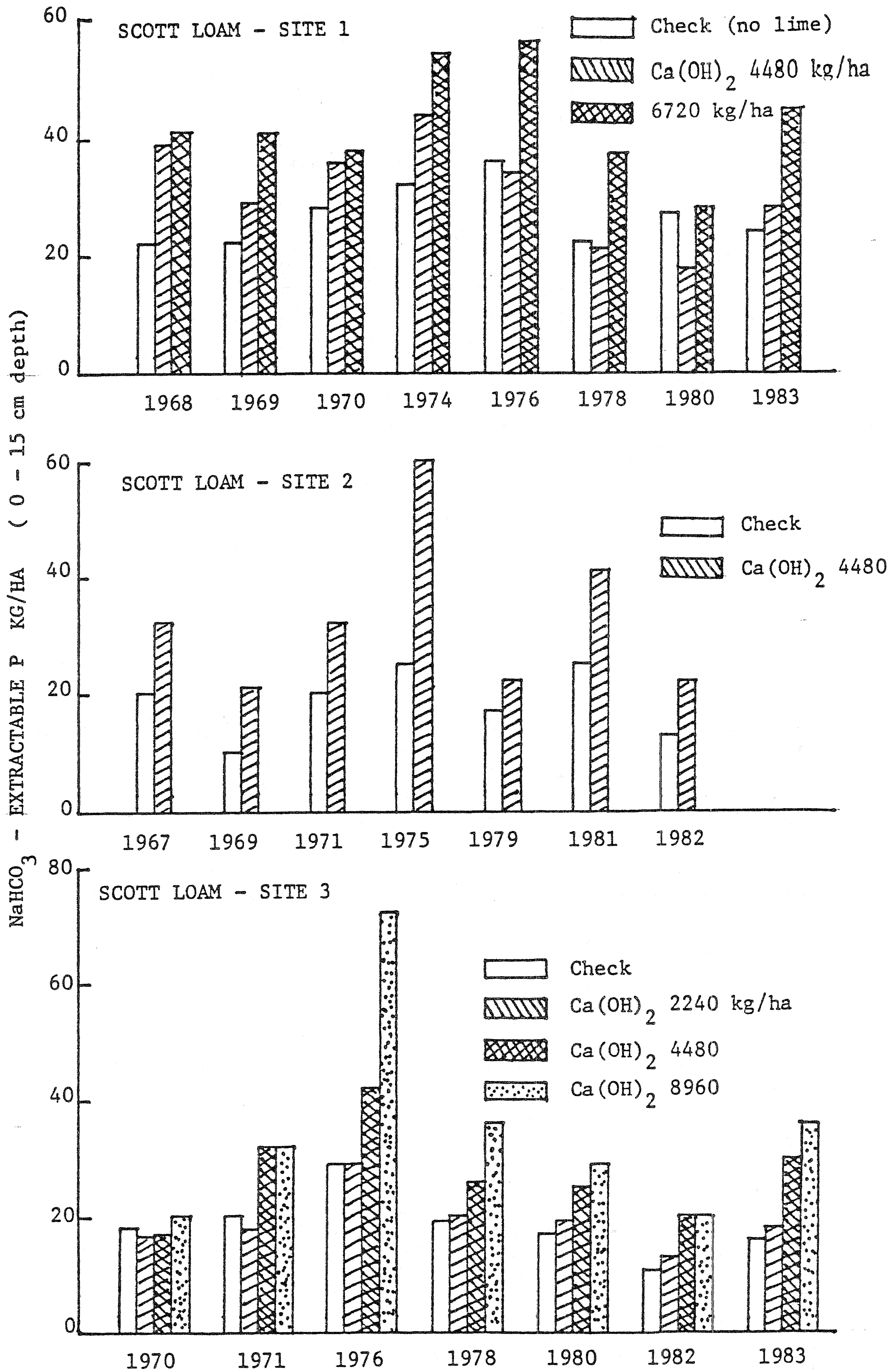

Figure 3. The effect of lime applications on $NaHCO_3$-extractable P levels in Scott loam.

Table 2. Effect of lime application on aluminum and mang anese contents in Scott loam - Site 1.

Lime kg/ha	0-7.5 cm			7.5-15 cm		
	Soluble Mn-ppm					
	1968	1970	1974	1968	1970	1974
0	40.4	37.0	22.0	20.0	11.4	17.4
4480	5.4	6.4	7.8	9.4	9.4	9.0
6720	2.6	1.0	3.4	5.2	1.4	4.9
	Soluble Al-ppm					
0	1.0	1.0	0.2	.6	.6	.6
4480	.4	.2	.1	.2	0	.2
6720	.2	.2	.2	0	0	0

Lime kg/ha	0-7.5 cm				7.5-15 cm			
	Exchangeable Mn (m.e./100 g)							
	1968	1974	1978	1981	1968	1974	1978	1981
0	.63	.52	.38	.46	.32	.31	.07	.26
4480	.18	.30	.24	.21	.22	.28	.07	.13
6720	.07	.19	.13	.07	.13	.18	.07	.06
	Exchangeable Al (m.e./100 g)							
0	.07	.09		.10	.05	.06		.06
4480	ND	ND		ND	ND	ND		ND
6720	ND	ND		ND	ND	ND		ND
	D.T.P.A. extractable Mn (ug/g)							
0	131			109	66			61
4480	62			68	46			36
6720	33			43	30			21
	Ammonium acetate extractable Al (ug/g)							
0	122	137		149	112	146		136
4480	43	56		57	81	68		61
6720	49	55		58	80	63		79

Lime = $Ca(OH)_2$

ND - not detectable

Table 3. Effect of lime application on the yields of wheat and barley on Scott loam - Site 1.

	Grain yield - kg/ha					
	Wheat				Barley	
	1983		9-crop Ave.		9-crop Ave.	
Treatment	No fert.	Fert.	No fert.	Fert.	No fert.	Fert.
Check	1372	2096	1261	1666	1734	2178
Gypsum	1438	1943	1319	1648	1949	2318
Lime 1	1930	2438	1592	1876	2246	2462
Lime 2	2319	2679	1955	2152	2578	2814

Lime 1 - $Ca(OH)_2$ @ 4480 kg/ha
Lime 2 - $Ca(OH)_2$ @ 6720 kg/ha

Table 4. Effect of lime application on the yields of wheat and barley on Scott loam - Site 2.

	Grain yield - kg/ha	
Treatment	No fertilizer	Fertilizer
	Wheat - 7 crop Ave.	
Check	1412	1762
Gypsum	1384	1704
Lime	1949	2083
	Barley - 9 crop Ave.	
Check	2033	2724
Gypsum	2227	2702
Lime	3011	3193

Lime - $Ca(OH)_2$ @ 4480 kg/ha applied in 1965

Table 5. Effect of lime application on the yields of barley and rapeseed on Scott loam - Site 3.

	Grain yield - kg/ha					
	Barley				Rapeseed	
	1983		7-crop Ave.		3-crop Ave.	
Treatment	No fert.	Fert.*	No fert.	Fert.*	No fert.	Fert.*
Check	1715	2661	2096	3126	1022	1425
Gypsum	1635	2752	2114	3040	1044	1386
Lime 2240 kg/ha	1850	2637	2178	3290	1119	1257
Lime 3360	1919	2766	2369	3101	1282	1416
Lime 4480	2325	2924	2820	3552	1490	1665
Lime 8960	2487	2948	3366	3603	1547	1570

*Fertilizer - M.A.P. 11-48-0 @ 38 kg P_2O_5/ha

as rates of lime increased up to 8960 kg/ha, raising soil pH above 7.5 (Table 5). Phosphate fertilizer also produced large yield increases on this soil, and liming appears to have improved the efficiency of phosphate fertilizers, as largest yield increases from P application were obtained on limed soil. On sites 1 and 2, lime applied at 4480 kg/ha produced yield increases of wheat and barley equal to or greater than those from 20-40 kg P_2O_5/ha without lime.

Annual variations in yields and response to lime were related to seasonal moisture conditions. There appeared to be no decrease in effectiveness of lime applied at 6720 kg/ha during the period of these studies. Rapeseed has responded somewhat less than wheat and barley to liming on this soil.

Protein and Phosphorus in grain

(a) Protein

Lime treatments had no consistent effect on protein content in barley on site 1, and only the highest rate of lime increased protein in grain on site 3. On site 2, however, there was a substantial increase in average protein content from the application of 4480 kg/ha of $Ca(OH)_2$. On this site there was also an increase in soil NO_3-N levels from liming (Figure 1). Protein content data are shown in Tables 6, 7 and 8.

(b) Phosphorus

Phosphorus contents in grain of wheat, barley and rapeseed were consistently higher on limed than on unlimed or gypsum treated plots on all sites, indicated improved uptake and utilization of soil and fertilizer P as a result of liming (Tables 9, 10 and 11). Contents of P in grain increased with increasing rates of lime.

Table 6. Effect of lime application on protein content in barley on Scott loam - Site 1.

Treatment	% Protein in grain (13.5% moisture) 3 yr. ave. No fertilizer	Fertilizer
Check	12.71	13.11
Gypsum	13.28	13.79
Lime 1	12.88	13.05
Lime 2	11.97	12.37

Lime 1 - $Ca(OH)_2$ @ 4480 kg/ha
Lime 2 - $Ca(OH)_2$ @ 6720 kg/ha

Table 7. Effect of lime application on protein content in barley on Scott loam - Site 2.

Treatment	% Protein in grain (13.5% moisture) 3 yr. ave. No fertilizer	Fertilizer
Check	12.37	13.74
Gypsum	12.03	13.11
Lime	13.90	14.14

Lime - $Ca(OH)_2$ @ 4480 kg/ha

Table 8. Effect of lime application on protein content in barley on Scott loam - Site 3.

Treatment	% Protein in grain (13.5% moisture) 3 yr. ave. No fertilizer	Fertilizer
Check	12.14	12.08
Gypsum	10.83	11.46
Lime 1	12.43	12.71
Lime 2	12.54	12.54
Lime 3	12.88	13.11
Lime 4	14.36	14.71

Lime 1 - $Ca(OH)_2$ @ 2240 kg/ha
Lime 2 - $Ca(OH)_2$ @ 3360 kg/ha
Lime 3 - $Ca(OH)_2$ @ 4480 kg/ha
Lime 4 - $Ca(OH)_2$ @ 8960 kg/ha
* Fertilizer - M.A.P. 11-48-0 @ 38 kg P_2O_5/ha

Table 9. Effect of lime application on P content in wheat and barley on Scott loam - Site 1.

	% P in grain - 4 yr. ave.			
	Wheat		Barley	
Treatment	No fertilizer	Fertilizer	No Fertilizer	Fertilizer
Check	.303	.296	.238	.256
Gypsum	.291	.291	.245	.260
Lime 1	.347	.335	.280	.290
Lime 2	.364	.360	.328	.335

Lime 1 - 4480 kg/ha $Ca(OH)_2$
Lime 2 - 6720 kg/ha $Ca(OH)_2$

Table 10. Effect of lime application on P content in wheat and barley on Scott loam - Site 2.

	% P in grain			
	Wheat - 1983		Barley - 3 yr. ave.	
Treatment	No fertilizer	Fertilizer	No fertilizer	Fertilizer
Check	.271	.260	.256	.276
Gypsum	.255	.273	.269	.283
Lime	.271	.289	.339	.357

Lime - 4480 kg/ha $Ca(OH)_2$

Table 11. Effect of lime application on P content in barley and rapeseed on Scott loam - Site 3.

	% P in grain			
	Barley - 4 yr. ave.		Rapeseed - 3 yr. ave.	
Treatment	No fertilizer	Fertilizer	No fertilizer	Fertilizer
Check	.264	.265	.564	.565
Gypsum	.232	.254	.499	.555
Lime 1	.247	.271	.562	.617
Lime 2	.288	.310	.615	.639
Lime 3	.311	.317	.609	.654
Lime 4	.328	.353	.619	.677

Lime 1 - $Ca(OH)_2$ @ 2240 kg/ha ; Lime 2 - $Ca(OH)_2$ @ 3360 kg/ha
Lime 3 - $Ca(OH)_2$ @ 4480 kg/ha ; Lime 4 - $Ca(OH)_2$ @ 8960 kg/ha
*Fertilizer - M.A.P. 11-48-0 @ 38 kg P_2O_5/ha

SUMMARY

The application of lime to an acid Scott loam produced the following results:

1. raised soil pH,
2. reduced the levels of soluble and exchangeable Al and Mn,
3. increased the levels of soil NO_3-N on one site and had no consistent effects on two sites, as measured by field sampling of plots,
4. consistently increased levels of $NaHCO_3$-extractable P in soil,
5. raised yields of wheat, barley and rapeseed substantially and improved phosphate fertilizer efficiency,
6. produced variable effects on grain protein levels in barley, and
7. consistently raised the levels of P in wheat, barley and rapeseed grain.

Under the dryland conditions in the area of the study the removal of applied lime by leaching appears to be slow, and one application of lime at rates of 4-6 tonnes/ha should persist for 20 years or more.

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